Low-Noise Receivers: 3-Kelvin Refrigerator Development for Improved Microwave Maser Performance

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A closed-cycle helium refrigerator with a 3-kelvin station has been built and tested. A 200-mW net refrigeration capacity was demonstrated at 3.1 kelvins. The system has been operated continuously for 1200 hours with no detectable degradation of performance. Reduced refrigerator temperature (from 4.5 to 3.0 kelvins) will increase the available gain and bandwidth, and reduce the noise temperature of microwave masers.

I. Introduction

4.5-kelvin closed-cycle helium refrigerators (CCRs) are currently used in the Deep Space Network with Microwave Masers at S, X, and Ku-band frequencies (Ref. 1). These versatile and reliable refrigerators have been described in detail previously (Ref. 2). The performance of a Microwave Maser can be improved substantially by reducing its physical temperature from 4.5 to 3.0 K. A previously described X-band maser (Ref. 3) achieves 45-dB net gain and has a theoretical noise temperature of 3.5 K (defined at the maser input connection at the final stage of refrigeration) when operated at 4.5 K. A reduction of temperature from 4.5 to 3.0 K will reduce the maser noise temperature from 3.5 to 2.0 K; the net gain will increase from 45 to 72 dB. The increased gain can be traded for additional bandwidth (Ref. 3).

II. Description of 3-K Closed-Cycle Helium Refrigerator

A 3-K refrigerator was built by adding counterflow heat exchangers, a 3-K expansion valve, a 3-K station, and a vacuum pump to a 4.5-K refrigerator. A simplified block diagram of the combined 4.5- and 3-K system is shown in Fig. 1. Compressed helium gas is supplied by, and returned to, a compressor identical to those used throughout the network. A pressure regulator is used to reduce the supply pressure to 3.04×10^5 N/m^2 (3 atm) for use in the 3-K portion of the system. The helium gas is cooled by the 70-, 15-, and 4.5-K stations, liquefying at about 5 K. The liquid experiences a partial vacuum in the 3-K station after passing through the expansion valve. The temperature of the boiling liquid in the 3-K station is determined by the absolute pressure in the 3-K station.

Efficient counterflow heat exchangers (same design as used in 4.5-K refrigerators) permit cooling of helium for the 3-K system with a minimum of heat being delivered to the 4.5-, 15-, and 70-K stations. Helium gas flow through the 3-K heat exchanger system is approximately 8 standard liters per minute.

A model 8815 DIRECTORR Sargent-Welch vacuum pump (free air displacement of 150 liters per minute) is used to maintain a partial vacuum in the 3-K station. Helium at 1.22×10^5 N/m^2 (1.2 atm) is sent from the vacuum pump to the compressor. The vacuum pump is shown in Fig. 2; its mounting versatility permits antenna-mounted operation with proximity to the 3-K refrigerator. Ucon-type lubricant is used in the vacuum pump and the compressor. Initial helium and lubricant purification is accomplished with a liquid nitrogen-cooled charcoal trap.

III. Performance

The 3-K CCR system produces 200-mW net refrigeration capacity at 3.1 K. 600-mW net refrigeration is available at 4.5 K in addition to the 3-K station capacity. Continuous operation for 1200 hours in the laboratory has demonstrated the feasibility of the 3-K closed-cycle helium refrigerator.

Additional work is needed to increase refrigeration capacity to 250 mW at 3.0 K. Further tests are required to assure adequate temperature stability and long-term reliability.

It is intended to use the 4.5-K station to intercept all heat loads except the pump energy dissipated within the maser at 3 K.

References

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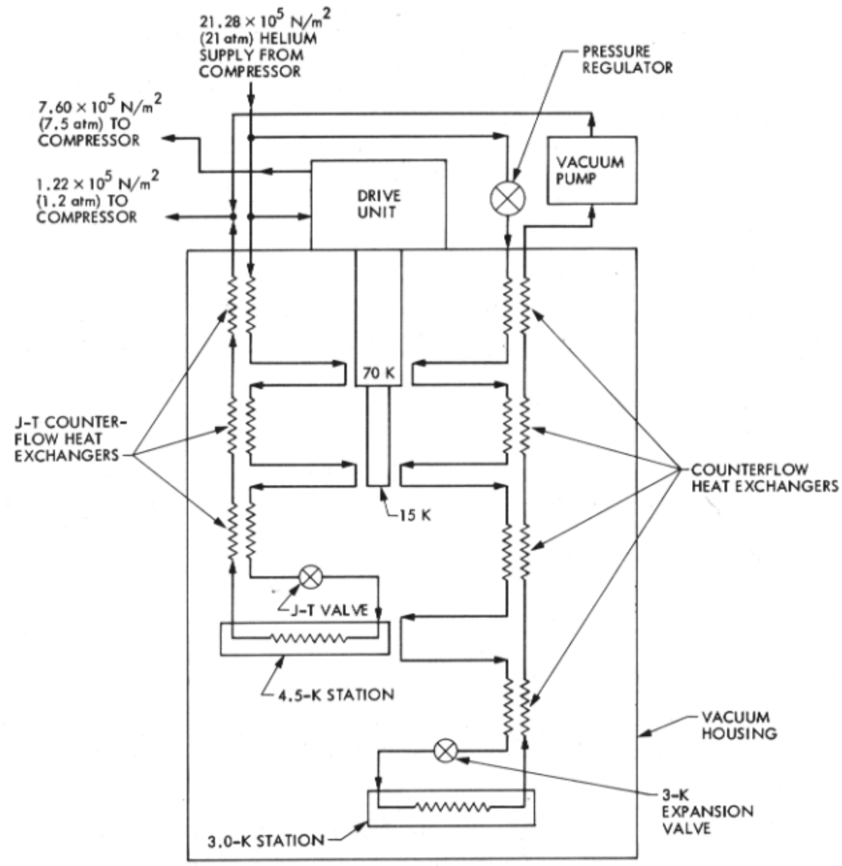

Fig. 1. 3-K closed-cycle helium refrigerator block diagram

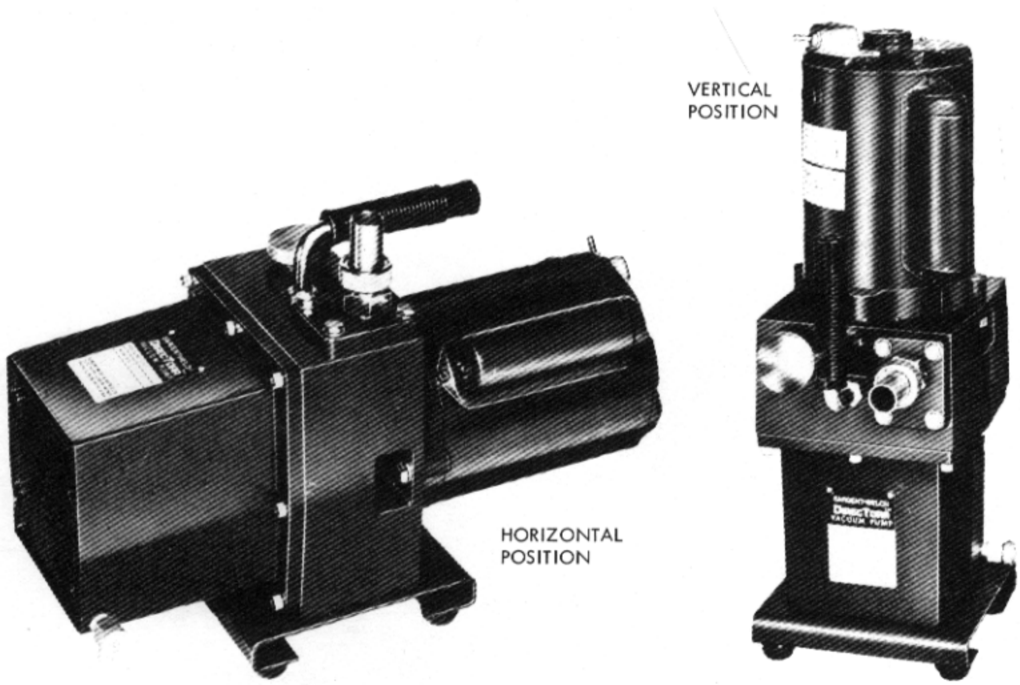

Fig. 2. Antenna-mountable vacuum pump for 3-K CCR